Improving Converge Casting Process in Collection Tree Protocol(CTP)

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Improving Converge Casting Process in Collection Tree Protocol(CTP)

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Certificate

This is to certify that the Major Project Report entitled **"Improving Converge Casting Process in Collection Tree Protocol(CTP)"** submitted by **Siddhartha Manwani (Roll No: 12MICT11)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Computer Science and Engineering of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project part-II, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

Many wireless sensor network applications, they rely on collection service to route the data to the sink. The Collection Tree Protocol is one of the best anycast tree based protocol used for data collection. It selects one of the trees to root having minimum cost routing gradient. Network lifetime is one of the major factors that have to be taken in to consideration for choosing the routing protocol. CTP used Expected Transmission ratio (ETX) metric for tree construction. It shows the total transmissions needed to send a packet to destination whose acknowledgment is received successfully. To improve converge-casting of CTP energy constrain and recovery bit is added into existing CTP. A new factor quality of forwarding (QoF) is also used to calculate for deciding the route to the sink. With that higher throughput and improvement in the lifetime of the tree was observed. The improved tree construction procedure has been implemented and simulation results are analyzed using metrics: No of packets received, Duplicate packets and Energy consumed.

Key words: Collection Tree Protocol(CTP), Quality of Forwarding, Energy added CTP, Recovery bit, Improving CTP.

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Abbreviations

CTP – Collection Tree Protocol

WSN – Wireless Sensor Network

ETX – Expected Transmission

ACK – Acknowledgement

THL – Time has Lived

SN – Sensor Network

QoF – Quality of Forwarding

Chapter 1

Introduction

Most sensor networks are collecting information depending on the type of application they are deployed. Sensor can be used to measure temperature changes at forest, pressure under the water pressure, to monitor micro-climate changes in agriculture farms. The nodes are used to collect information using their sensor and send these readings to central base station using multi hop wireless communication. In the domain of battlefield surveillance, climate monitoring system, security control for homes and offices, this wireless sensors are deployed to collect and send the data to the sink where it is further processed. For such network, the hierarchical architecture is widely used in which distributed sensor nodes are grouped into various segments, namely clusters, with each cluster has a head.

Within the last few years data collection in wireless have been developed. Of all the algorithms developed, Collection Tree Protocol is used as reference protocol.[5] A remote sensor system is an ad hoc system with various sensor nodes conveyed at wide geological territory. Once deployed it can gather information about physical quantity like temperature, weight, pressure etc. Remote sensor systems comprise of tiny low power nodes with sensing, computational and wireless communications capabilities that might be conveyed arbitrarily or deterministically in a region from which clients wish to gather information. At that point these sensor readings are appeared for the sink node where they are further processed or sent further as per the necessity. A sink can send these bundles to outer connections utilizing solid wired correspondence join. Node need to send the packet through directing tree up to one of its sink node. Every node chooses one of its neighbors as parent node relying upon the link quality. This parent node takes the data packet from the child node and advances it to the sink or towards the sink. Nodes collect data from its neighboring nodes to select the parent node using beacon packets.

The main purpose of CTP is to collect data. It is best anycast protocol. Some nodes advertise them as root nodes. In CTP packet is communicated to any available root of the network having minimum cost. Remaining nodes uses this advertisement to connect to the collection tree. These nodes form a set of routing trees to the sinks. CTP is a address free protocol in which a node does not select the sink node, it only chooses the next hop and implicitly selects the root. CTP uses the routing gradient ETX (Expected transmission). CTP assumes that it has the link quality information of some nearby nodes so this provides an estimate of transmission required to successfully send a packet and receive its acknowledgment.

1.1 Objective

The objective of this research is to identify and evaluate the performance and challenges for collection tree protocol for WSN applications against set of qualitative performance metrics relevant for any routing protocol.

The goals of this research include:

- To study, evaluate and simulate existing Collection Tree Protocol.
- To propose improvements for Collection tree Protocol.
- To test the results of proposed improvement with existing Collection tree Protocol.

1.2 Thesis Contributions

- Identify the key drawbacks of current CTP through literature survey.
- Implement the enhanced CTP protocol to solve this drawbacks and compared with benchmarks results.

Chapter 2

Collection Tree Protocol

CTP uses beacon messages for constructing and maintaining the collection tree. It has two features efficiency and reliability. CTP should send a unicast data packet with minimum cost. The implementation of CTP is described in.[1] This protocol will make one or more routing trees to the root which is called base station. CTP is having a routing issue which will lead to routing loop and thus will have system congestion. Because of network congestion packets will drop . Due to frequent changes in link quality it will have stale topology. It has two mechanisms to solve this problem. The data path validation uses transmission and reception methodology. By sending packet to route dynamically and detecting when it is not making progress towards sink. Second is adaptive beaconing which is governed by trickle algorithm. In this nodes can send very few beacon messages when topology is consistent. ETX of root is always zero and ETX for a node is characterized as summation of ETX of its parent along with the ETX of connecting link to its parent. CTP always chooses the path having least ETX value. If any node receives ETX value which is higher than its own then there will be a routing problem and eventually loses connectivity with a candidate parent.

How tree is constructed: CTP uses ETX as routing gradient. Parent has higher gradient value. Each parent knows about its children id below it. Each node in lower level will send packet to the node which is having lower ETX value and are in communication range. Parent will send the packet up to the tree which are at intermediate level. Finally packet is route to the root node.

As ETX routing gradient is used to transmit packet. The root always has least ETX of 0. The path with the lowest ETX value is selected for routing packet. Routing loops are a problem that can emerge in a CTP network.

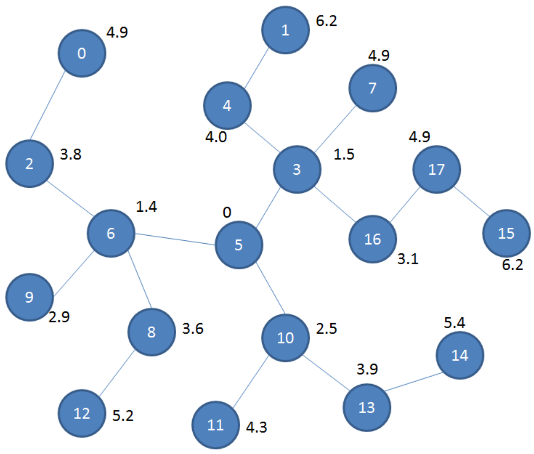

Figure 2.1: CTP Tree construction

CTP address loops by two mechanisms. First, each packet contains node current gradient value. If node receives any data packet with the gradient value lower than its own, then this shows inconsistency in the tree. CTP tries to solve this problem by broadcasting the beacon packet in hope of that sender node will hear it and changes its routes accordingly. If some collection of nodes is separated from the other nodes, then the ETX of this group will increase forever. Packet duplication is also a problem that can occur. This problem occurs due to loss of acknowledgment packet. So the sender sends it twice and receiver receives the same packet twice. This can have very bad effects over multiple hops. For example, if each node produces one duplicate packet, then on the first hop there will be two packets and on second it will be four and keeps double on each hop. Which results in receiving more than one packet. CTP has an additional time has lived(THL) field, which routing layer increments on each hop. [1]

2.1 Architecture

The architecture of Collection Tree Protocol is shown in figure 1.1. The main CTP Routing compound module has three components Link Estimator, Routing Engine and Forwarding Engine& also include CTP protocol module. CTP Protocol provides functionalities by managing all the outgoing and incoming messages between internal components.

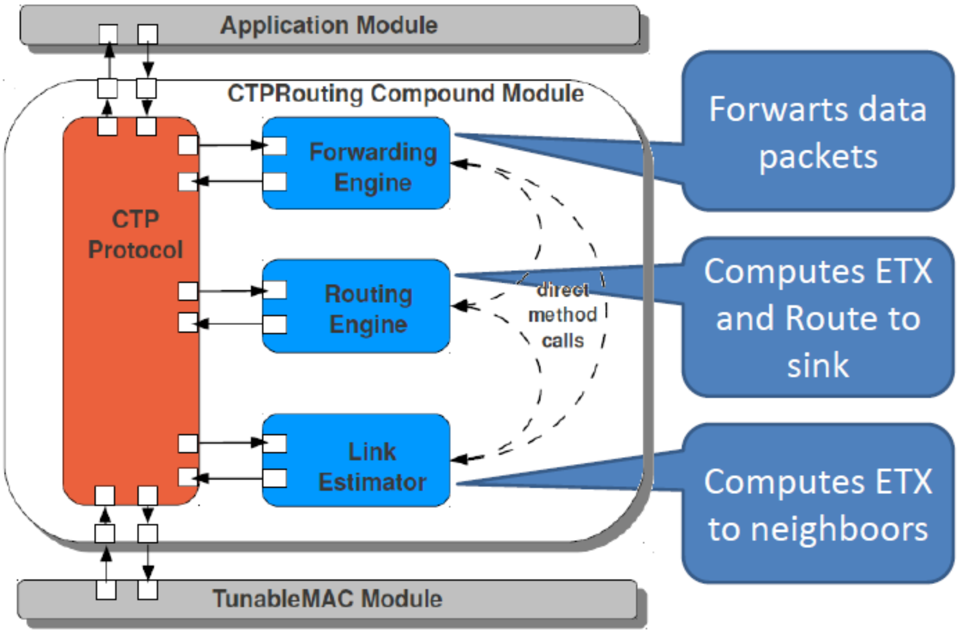

Figure 2.2: CTP Architecture [1]

So only the CTP Protocol module is connected to the ingoing and outgoing gate of CTP Routing module. LE, FE & RE use this CTP protocol module to send their messages to internal or outer modules. In figure the dotted lines are direct method calls. The internal modules of compound module can use same set of functions. Means this function may be implemented in one module and used by other direct calls. To interact with application layer CTP Routing module uses Application module and to interact with physical layer uses Tunable MAC module.

The structure of both information & routing message used by CTP is discussed next.

2.2 CTP Routing and data packets

CTP trade information and routing messages for tree development & support and to collect data at sink. Structure of CTP Routing, Data & Acknowledge packets are shown in figure 2.2.

PHY and MAC overhead: Both routing & data packet incorporate 6 bytes of the PHY header, 80 bits of MAC header and 16 bits for MAC footer. Mac footer incorporates Frame check Sequence (fcs). In FCS 1byte is RSSI (received Signal Strength Indication)

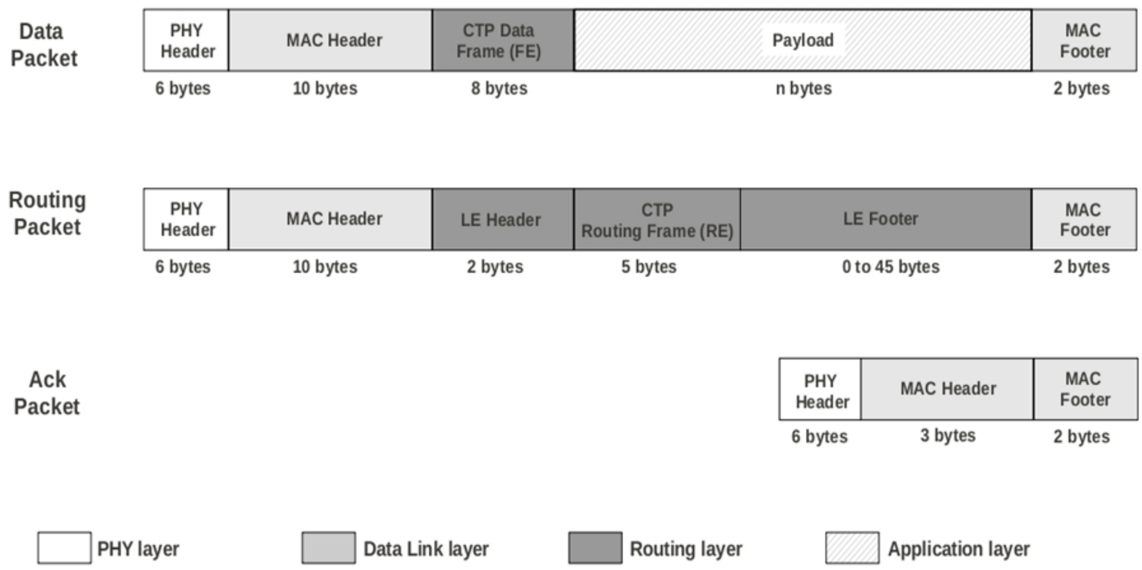

Figure 2.3: Structure of Data, Routing & Acknowledgement packets [2]

which is utilized for Link Quality Indication (LQI).[10]. Inside Castalia, the Tunablemac module manages to set this value and to add them to travelling packets.

CTP data frame: Before packets are gone to radio,they are taken care of by FE, which plan their transmission at routing layer. FE includes 64 bits of information to control travelling data packet FE adds this 8 bytes data frame. Fig 2.3 shows detailed description of it. First bit is P(Pull) Flag used to indicate topology update demand from the neighbors by sending beacons, and second bit is C(congestion) flag,in the event that a node gets a directing guide from a neighbor. If C flag is set quit sending packet to that particular neighbor and search for other available routes. The THL (Time Has Lived) is a counter and it is augmented by one at every packet sending which shows total hops packet has gone before arriving at the current node. The next two bytes that is 3^{rd} and 4^{th} byte are used for (multi-hop) ETX. Then the remaining bytes are Origin field, indicates the origin of packet, SeqNo field includes sequence number of the packet which is defined by origin, CollectId is used as identifier for specifying instance of collection service is intended to handle the packet.

CTP Routing frame: Routing packets are used for constructing and maintaining tree. LE adds 2 bytes header and variable length footer in routing packet. CTP routing frame is filled by routing engine as shown in figure. First two bits in data frame and

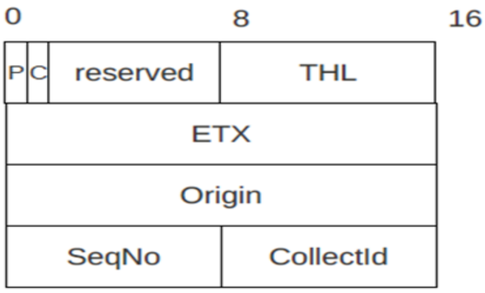

Figure 2.4: CTP Data Frame [1]

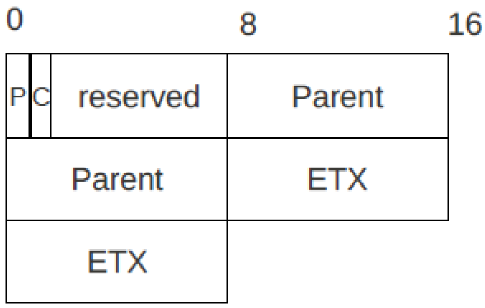

Figure 2.5: CTP Routing frame[1]

routing frame are same. Parent node is used for to specify the parent of the node sending the beacon. ETX field has multi-hop ETX metric, and stores over 2 bytes and 1-hop ETX need only 1 byte.

Acknowledgments: Acknowledgement packets are used to show successful reception of data packets. CTP uses link-layer acknowledgment packets, so it uses only PHY and MAC layer information consist of 11 bytes.

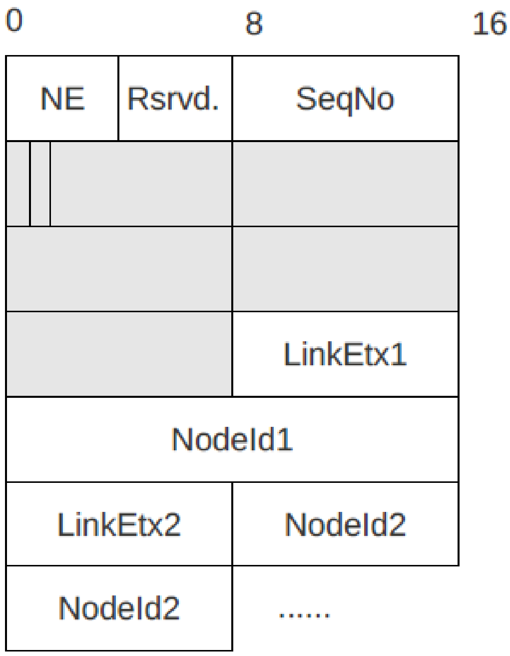

Figure 2.6: LE header and footer

Chapter 3

Components of CTP

CTP has three main components:Link Estimator(LE), Forwarding Engine(FE) and Routing Engine(RE).

3.0.1 Link Estimator Module

The quality of communication link is determined by the Link Estimator.

LE header and footer: The header and footer structure added to routing packet by LE prior to they are sent to radio for transmission is shown in figure3.1. In the first byte the four bits are NE (Number of entries) field, indicate how long is the footer and the other four bits are not used, can be used in future. The second byte consists of SeqNo field, shows the sequence number and that is incremented by one whenever a beacon is transmitted. This field is used to determine the number of missing beacons. The footer has variable number of <etx , address>couples , each of 3 bytes in length , including the 1-hop ETX (1 byte) and the address (2 bytes) of neighboring nodes.

Computation of the 1-hop ETX: For determining 1-hop distance for each neighbor LE considers the quality of both the inbound and outbound links. To compute outgoing link [3]

$$Q_u = n_u/n_a \tag{3.1}$$

Where n_u is the total unicast packets sent by the node, even counting the retransmission packets also and n_a the corresponding number of received acknowledgments. If $n_a = 0$ then Q_u is set to total number of failed deliveries from the last successful delivery.

To compute corresponding (ingoing) link. [3]

$$Q_b = n_b/N_b \tag{3.2}$$

Where n_b is the amount of beacons gained by a node from a particular neighbor and N_b is the aggregate number of beacons broadcasted the same neighbor. Let Q be the new value of either Q_u or Q_b and ETX_{old} 1hop the previously computed value of the 1-hop ETX. The updated value of the ETX_{1hop} is then computed as follows:[3]

$$ETX_{1hop} =_{\alpha Etx} Q +_{(1-\alpha ETX)} ETX^{old}_{1hop} \tag{3.3}$$

After each one update, the worth of the 1-hop ETX is put away in the link estimator table along with comparison to neighbor identifier.

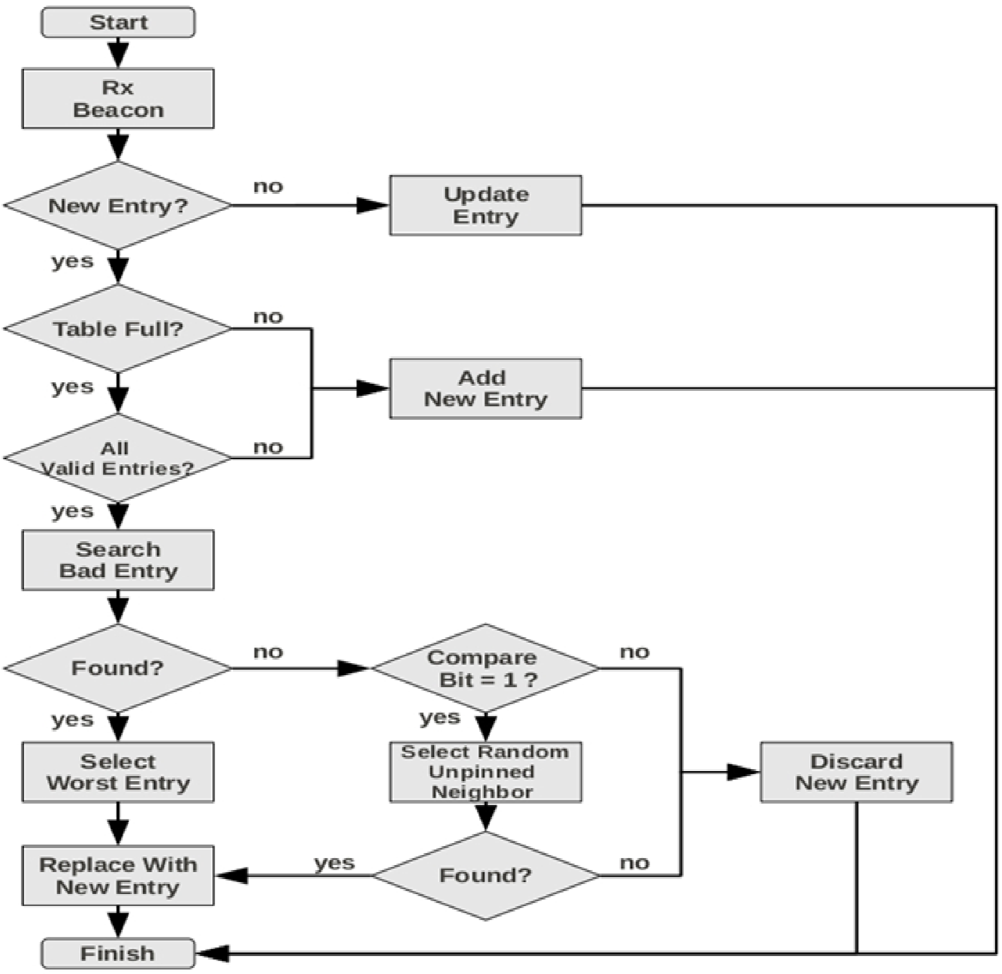

Figure 3.1: Insertion policy for LEs link estimator table

Insertion/eviction procedure of the link estimator table: At the point when a node accepts a beacon from the node that is not entered in the link estimator table, LE checks if there is a free space accessible to allot new found neighbor. If space is accessible it basically embeds new entrance in one of the accessible free spaces.

If the table is filled and has at least one entry that is not valid, then LE basically replaces non legitimate entrance with the new neighbor. In the event that the LE table is filled and all entries are not valid, then LE verifies if there exist (valid, mature and non-stuck) sections whose 1-hop ETX is higher than a given threshold. Among these entries the node with the maximum 1-hop ETX is replaced by new neighbor.[1]

If LE does not have any eligible entry to remove from the table, then LE decides whether to insert the new neighbor or not. The LE can forces the insertion in following two cases, First if it is one of the root of routing tree. Second if the multi-hop ETX declared in the received beacon is lower than at least one of the eligible entries of the routing table. Flow of Eviction/insertion procedure of the link estimator table is shown in Figure 3.1.

3.0.2 Routing Engine

The primary undertaking of Routing Engine is to send beacons, fill the routing table, to keep it up to date, and to select next hop in routing tree towards which requisition information must be directed.

Frequency of beacons sending: To control the frequency of the beacon packets Trickle algorithm is used.[4] Using Trickle a beacon is sent at a random instant within a given time interval, whose minimal length I_b^{min} is set a priori.

The length I_b will be doubled after each successful transmission. So as to avoid a long absence of beacon transmissions, a maximal length of the sending interval, which is referred as I_b^{max} .

Some particular events can lead to reset of the value of I_b. Such events are the detection of: a routing loop; a congested node; a node with the pull (P) flag set.

Parent selection procedure:[1] The procedure of selecting parent is repeated periodically or when one of the events occurs: beacon is sent, a neighbor is not reachable, neighbor is no longer congested, current parent gets congested, no route to sink.

3.0.3 Forwarding Engine

The main feature of Forwarding Engine is to forward packets received from neighbors and also to send packets generated by application module. It also recognize duplicate packets and routing loops.

Packet queue and retransmissions: To forward a packet, FE receives the Id of parent from RE. If Parent is not congested FE calls for second procedure of sending packet by appending 8 bytes long CTP data frame. Or , if the parent is congested, it waits till the congestion status is changed or a new parent is selected. After sending the FE waits for the acknowledgment. If the acknowledgment is not received within the given time interval, FE will retransmit until the maximum transmission limit has been reached. After the maximal retransmission if acknowledgment is not received then the packet is discarded.

Congestion flag: If one node has to perform many retransmissions attempts, the FE queue will quickly fill up with unsent packets. FE declares node as congested as soon as half of its packet queue is full and sets congestion flag. And also notifies it to RE module, which sets C flag in routing frames to 1.

Duplicate packets: Origin specifies identifier of node which is source of the packet. SeqNo is the sequence number of the current frame, and THL is the hop count of packet. CollectID specifies instance of CTP. B comparing this value of the tuple with the tuple of the incoming packet, FE can detect duplicate packets.

Routing loops: The FE also detects the routing loops. To this end, the FE compares the (multi-hop) ETX of each incoming packet with the (multi-hop) ETX of the current node. ETX of the sending node must be higher than the receiving node. If this is not the case it starts LOOP backoff timer, resets the beacon sending interval and sets the pull flag to 1 to force a topology update. The Loop timer is higher than the beacon sending interval.

Backoff timers: FE also has the backoff timer for collision avoidance mechanism. In particular, the FE sets the TX_OK, TX_NOACK, CONGESTION and LOOPS backoff timers. The first clock is started after every fruitful packet transmission to adjust channel reservation between nodes. The second has the same function however is enacted if the expected recipient of a packet fails to return the corresponding acknowledgment. The CONGESTION backoff timer is started when a congestion status of the selected parent is detected. The LOOP timer starts when a loop is detected.

Chapter 4

Literature Survey

The following section briefly describe the papers studied and the most important points are also mentioned.

In [3] they have implemented CTP in Castalia 3.0 which is based on OMNET++[8] . The author has given brief explanation regarding implementation of CTP, and how it differs from actual design of CTP. The MAC module in Castalia is T-MAC (Tunable -MAC) which does not have all the features needed for CTP, So following changes has been made in MAC to make it similar to TinyOS implementation. The primary modifications incorporate progressions to queue length, including snooping component, connection layer affirmations and changes to back off clock. This back off timer will decide delay in transmitting the packet when channel is free and when it is busy. It is very important parameter as small value of it can cause increase in number of retransmission and high value results in queue fill up.

The set of important metrics to evaluate performance of CTP includes data delivery ratio, control overhead, hop count and the number of duplicate packets. The simulation study shows that number of nodes sending the packets is inversely proportional to the data delivery ratio. And there are more chances of collision of packets as more packets are travelling in the network. As distance between the sink node from the relay or source node increases the nodes transmission range a significant performance hit is observed. This so happens because of the re-transmissions needed for successful transmission. As queue gets full so no new packets are accepted by the node and are dropped. The simulation shows that control overhead which is ration of data traffic to the control traffic decreases as the probability of number of nodes sending data simultaneously increases.

This is due to additional data packets traveling in network which reduces control packets needed for routing tree maintenance. If a cluster of nodes are disconnected from the other nodes in the network, high control overhead will be observed as nodes frequently exchange control packets with sink node.

Though energy consumption and route changes are very important feature in the design of mobile sensor routing protocol. However, the research on CTP so far has focused on static network scenarios only, by reducing energy utilization of the nodes and increasing network lifetime.

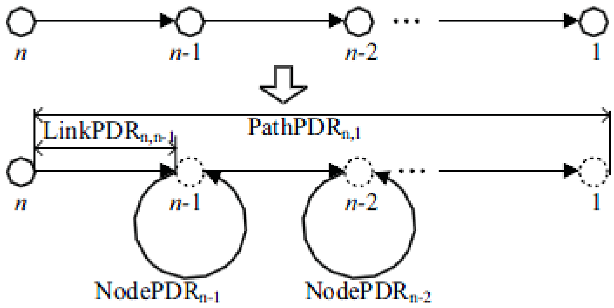

Figure 4.1: Architecture of ELQR [11]

In [11] They have proposed ELQR which considers residual energy as major factor before selecting the route. In CTP the node with better quality of the link is selected as parent and drains fast resulting in the network disconnection. In order to avoid such condition a routing protocol is proposed to balance the load among the other possible routes. This can be achieved only when residual energy is taken into consideration for selecting parent and this information is exchanged between the neighboring nodes. The suboptimal routes are selected but network lifetime is increased. But how to measure energy metric is a challenge in ELQR. There is no hardware supported energy measurement, so only way to do is software measurement. This residual energy is updated in the routing table. This is simulated in TinyOs networks and showed increase in network lifetime comparing to CTP. But Packet Reception Rate is less than CTP as it takes more time in converging whenever a change in the route occurs. This work is very helpful in testing only static scenarios of CTP.

In [7] QoF paper they have showed a new approach for dynamically routing packets.

In this paper instead of considering the ETX value ETC value. ETC differs from ETX in that it not only considers link quality but also retransmission limit .When $r \rightarrow \infty, ETC = ETX$. When r equals to a fixed number. ETX overestimate the transmission count while ETC reflects the actual transmission count under retransmission limit r.

They define QoF of a generic link as ratio of the data delivery ratio to the actual transmission cost. $QoF = \frac{PDR}{ETC}$. . The packet loss is mainly due to two reasons.

1. The transmission timeout on the links (exceeding the retransmission threshold).
2. Local packets drops within the node which are mainly due to receive / transmit queue overflow, packet duplication, routing loops.

The link-Qof not just recognizes the transmission cost at the sender additionally considers the data delivery ratio at the receiver. The node-Qof gauges the nature of sending inside a node, and it assumes an essential part in differentiating the problematic nodes. They have also considered the network yield giving us the good put of the network, reflecting both forwarding reliability and the throughput

$$yield = \frac{\underline{no.\ of\ data\ packets\ received\ at\ sink\ during\ w}}{no.\ data\ packets\ sent\ by\ all\ nodes\ during\ w}$$

In [9] the topology is mutually controlled by the system format and the link dynamics. The effective topology over which routing ways are built additionally depends on the decision of routing destination, which compares to the sink situation in the setting of WSN. The synthesis of the network layout, the link dynamics and the sink arrangement, which is essentially allude to as system topology, has a substantial effect on protocol performance execution. For this purpose, they introduce a protocol-independent network metric, the Expected Network Delivery (END), that captures the reliability of the achievable routing paths from each node to the sink. The END quantizes the delivery performance that a collection protocol can be expected to achieve given the network topology. They showed with various experiments that END computed were able to conclude that the performance variations were primarily due to the properties of the topology present during those experiments rather than the protocol mechanisms. Then the Expected Path Delivery (EPD) e_k from node k to the sink s is computed as,

$$e_k = \prod_{h=0}^{H-1} \lambda_{rh,rh+1} \tag{4.1}$$

Where r_h represents the h^{th} hop between k and s. H denotes the number of links that form the route between k and s.

$$END = \frac{1}{|N|} \sum_{k \epsilon N} e_k. \tag{4.2}$$

In order to quantify the expected performance of a collection protocol with a global knowledge of the network topology, this topology-aware collection metric is defined as the Expected Network Delivery (END), denoted as $END\epsilon[0;1]$. The next chapter describes the observed problems in CTP and proposed approach to solve the these problems.

Chapter 5

Problems and Proposed Approach

5.1 The problem

Collection Tree Protocol does not consider energy of individual node for tree construction, so may select a node which is having low energy than threshold, so might result in network breaking. In CTP, tree is constructed based on Expected Transmission count (ETX). In CTP beacons are used for table updating and frequency of which is doubled on each successful packet transmission. It is controlled by Trickle Algorithm. The node will not get the knowledge of the broken link until reception of the beacon, which can result into high packet loss and retransmission of packets. CTP considers the quality of the link probability of dropping the packet at link. But CTP does not consider "problamatic" nodes that drops a portion of packet. That can also increase the number of retransmissions by not knowing that the node is problematic.[7]

5.1.1 Proposed Approach

To overcome this problem, a new method for selecting the path is proposed. Where in the existing CTP uses ETX for selecting the path. In this method energy of the parent node is also considered along with ETX. The following equation shows calculation of new multi-hop ETX.

$$MaxEnergyMinETX \leftarrow 0.5 * 50 * ETX_{1hop} + 0.5 * (5/(Energy * 2)) \tag{5.1}$$

In CTP the node will come to know about the broken link when it will receive the beacon. But as to save energy , the beacon transmission interval has been doubled after

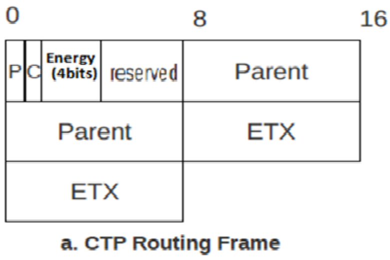

Figure 5.1: CTP Routing frame

each sucessful transmission. The minimum beacon interval is set to 128 and the maximum is set to 512,000.[12] So the node will recognize that parent has ran out of energy, hence packet drop ration is increased.To overcome the problem a new approach is defined which uses recovery packet. When a node has energy value lower than the threshold energy it itself sends this recovery packet to its neighbors to make them aware about its energy reduction. In CTP data frame, 1 bit reserved flag has been used for recovery bit as shown in the figure 5.2. If R flag is set to 1 than it is recovery packet otherwise it is data packet. In CTP data frame which is field of recovery packet, includes 1bit R flag

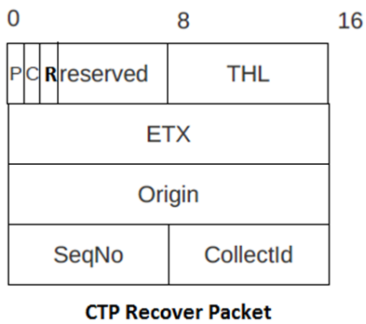

Figure 5.2: CTP Data frame

into reserved field which is shown in figure 5.2 If R flag is set than node knows that this packet is recovery packet otherwise it is data packet.

So as to solve such problem nodes history is also taken into consideration for selecting parent along with the residual energy and link quality. So that CTP can avoid the problematic nodes from selecting them as parent.

$$S_{pr} = (0.2) * residualenergy + (0.5)(Maxlength - queuelength) + (0.3)q_b \qquad (5.2)$$

S_{pr} = suggested Parent

Max length = no. of max allowed packets that can wait in the queue.

Queue length = no packets waiting in the queue.

q_b = quality of inbound link from that node.

Then this S_{pr} value is added with the link quality parameter, and the remaining procedure is same as CTP. So higher this value will have higher Probability to reach the sink nodes.

The next sections contain implementation of proposed algorithm and their comparison with existing CTP.

Chapter 6

Implementation Details

Castalia is the simulator for Wireless Sensor Networks, Body Area Networks and generally used to simulate low-power embedded device. It uses OMNET++ platform. Castalia can simulate a large range of platforms. So sometimes used to evaluate different platforms. The feature of Castalia are:[13]

- Maps of path loss are shown in model along with connections between nodes.
- Sense device noise, bias and power consumption.
- MAC and routing protocol available.
- Designed for adaptation and expansion.
- States with different power consumption and delays switching between them.
- Extended sensing modeling provisions.

The Castalia 3.0 version is used for simulating the CTP and proposed approach.

6.1 Using Residual Energy for Parent Selection

- RoutingTableUpdateEntry() of the existing CTP was modified so that the 4-bit residual energy of the nodes can be added in routing table, and can be used and processed later for the parent calculation.

- Node's energy was bound into the routing packet's reserved bits. The send BeaconTask() was modifed for binding the energy into beacon so the node can inform its neighbor about its residual energy.
- Calculation of parent selection procedure was also altered by which considers residual energy into consideration, to avoid the sudden drain of particular node by selecting the same parent.

6.2 Recovery Bit in Data Packet

- Before sending the data packet node will check its remaining energy if it is below the threshold and less than the average of all the connecting nodes , it will set the recovery bit in the data packet.

  ```
  void CtpForwardingEngine::sendTask()
  .....
  double t_energy= 0;
  // t _energy i uses to sum the energy of all the connected nodes , and then i will take average of it.
  for (int sand = 0 ;sand < cre → routingTableSize;sand ++)
  {
  t_energy=t_energy+cre → routingTable[sand].info.remainEnergy;
  }
  double avg_energy = t_energy/cre → routingTableSize;
  command_CtpPacket _setOption(qe → msg, CTP_OPT_REV);
  .....
  ```

- Now if packet with recovery bit set is received then new parent is calculated.

  ```
  void CtpForwardingEngine::eventSubSnoop_receive(cPacket* pkt)
  {
  if (command _CtpPacket_option(msg,CTP_OPT_REV))
  cre→ updateRouteTask();
  ```

- Then the recovery bit is cleared.

  ```
  command_CtpPacket_clearOption(msg, CTP_OPT_REV) ;
  ```

6.3 Suggested Parent

The above mentioned changes of residual energy are assumed to be done. command_CtpInfo_getEtx() was modified so that the new formula for parent selection can be calculated. This formula should consider the node current load its past history and remaining energy.

- Current load shows that how busy is that particular node.
- Past history is very important parameter as it determines whether the node is problematic. So that loss of packet at node can be reduced.
- Remaining energy to balance load in the network and to increase network lifetime.

Chapter 7

Simulation Results

7.1 Simulation parameters for CTP, CTP-E and CTP-ER

Before starting simulation, the simulation scenario parameters were set during simulation are:

Parameter	**Values**
Field Size	125x125,175x175 ,200x200
No. of Nodes	50,100,150,200
Topology	Uniform
Initial Node Energy(joules)	63
Simulation Time(Sec)	300,400,500,600

Table 7.1: Simulator Parameters

7.1.1 Simulation comparison for CTP and CTP-E

In this sub-section, the total Number of Packets received, Duplicate packets, Consumed energy and Network Lifetime of the original CTP and CTP-E (Residual Energy added CTP) have been analyzed.

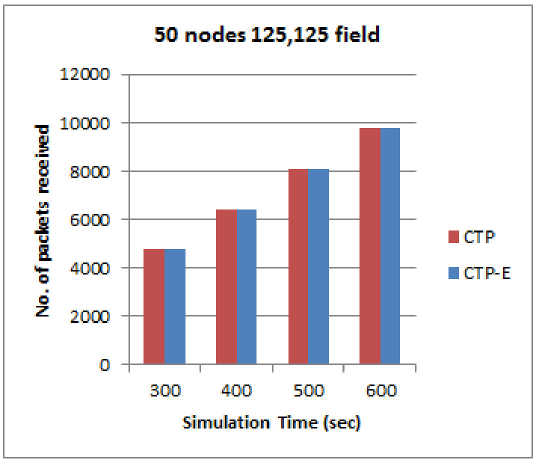

Figure 7.1: Simulation for field size 125,125 (meters)

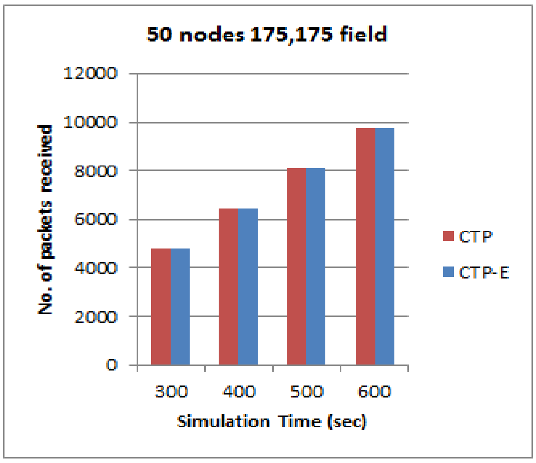

Figure 7.2: Simulation for field size 175,175 (meters)

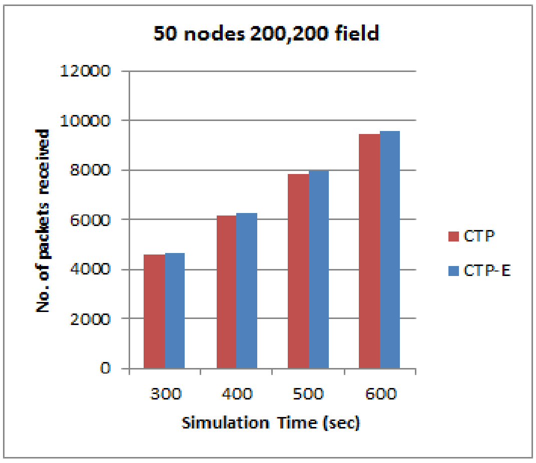

Figure 7.3: Simulation for field size 200,200 (meters)

Figure 7.4: Comparison of existing CTP andCTP-E

The received number of packets are more or equal for CTP-E than the original CTP. And also the number of duplicate packet received is less for CTP-E than original CTP. Hence overall throughput is increased.

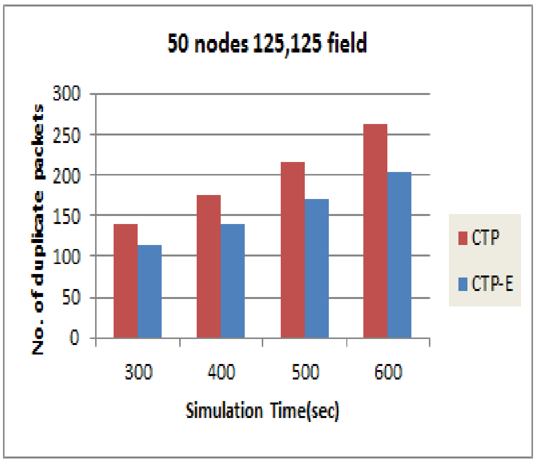

Figure 7.5: Simulation for field size 125,125 (meters)

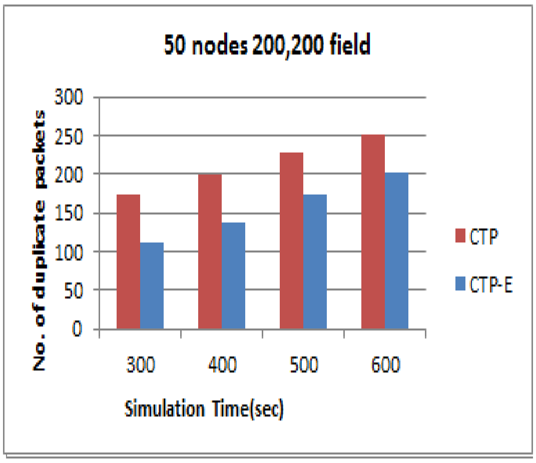

Figure 7.6: Simulation for field size 200,200 (meters)

Figure 7.7: Comparison of existing CTP and CTP-E

As duplicate packets are reduced from received packets the overall performance of CTP-E is better than original CTP.

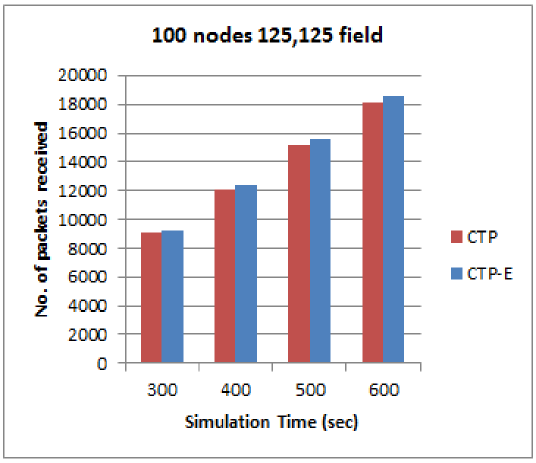

Figure 7.8: Simulation for field size 125,125 (meters)

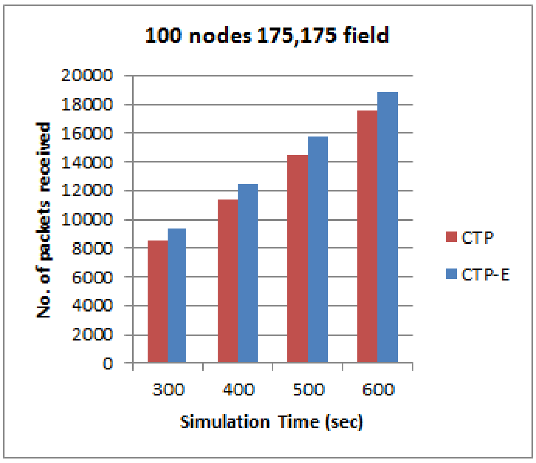

Figure 7.9: Simulation for field size 175,175 (meters)

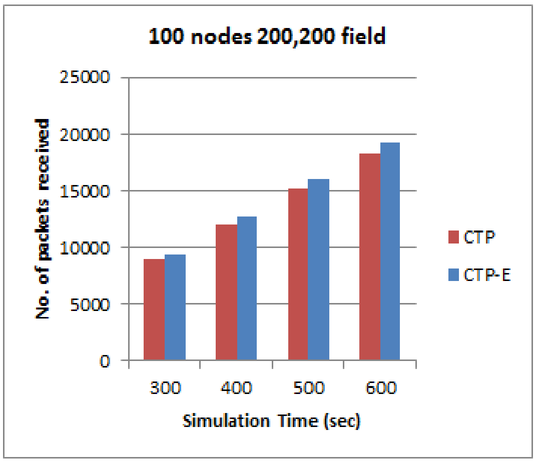

Figure 7.10: Simulation for field size 200,200 (meters)

Figure 7.11: Comparison of existing CTP and CTP-E

The figure 7.11 shows that for node 100 with varying field size and simulation time the CTP-E is performing better than existing CTP. As the received packets are more in CTP-E.

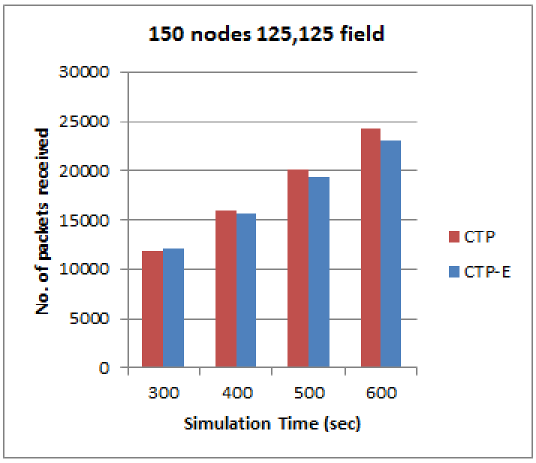

Figure 7.12: Simulation for field size 125,125 (meters)

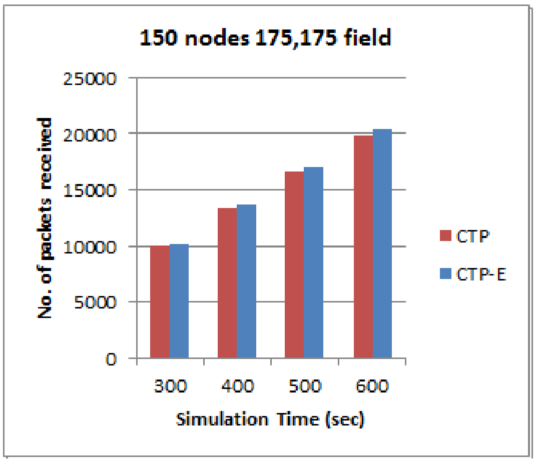

Figure 7.13: Simulation for field size 175,175 (meters)

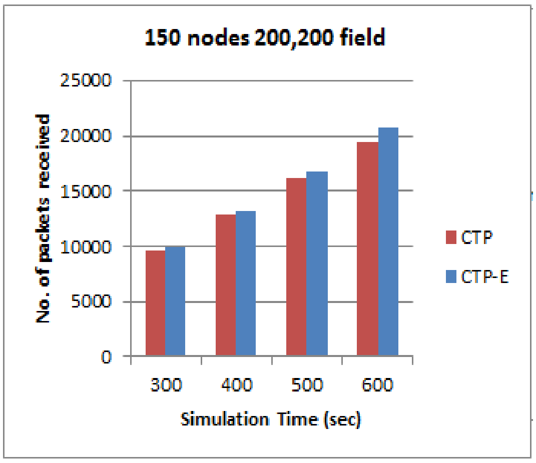

Figure 7.14: Simulation for field size 200,200 (meters)

Figure 7.15: Comparison of existing CTP and CTP-E

The figure 7.15 shows that for different field size and simulation time the received packets are higher for CTP-E than original CTP.

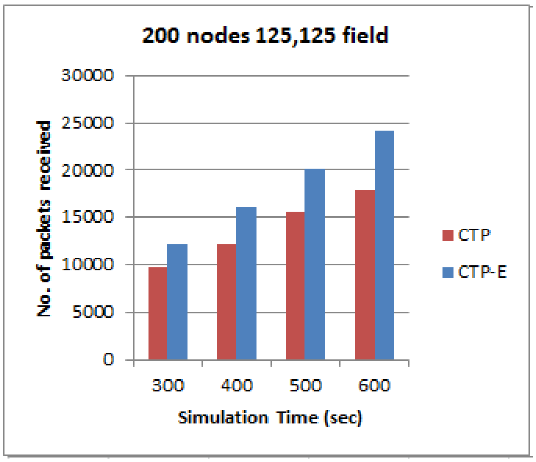

Figure 7.16: Simulation for field size 125,125 (meters)

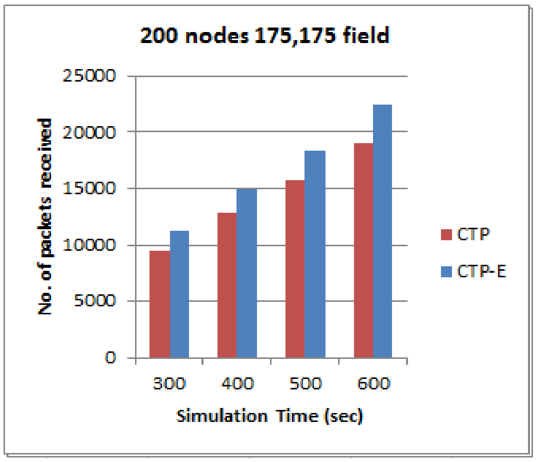

Figure 7.17: Simulation for field size 175,175 (meters)

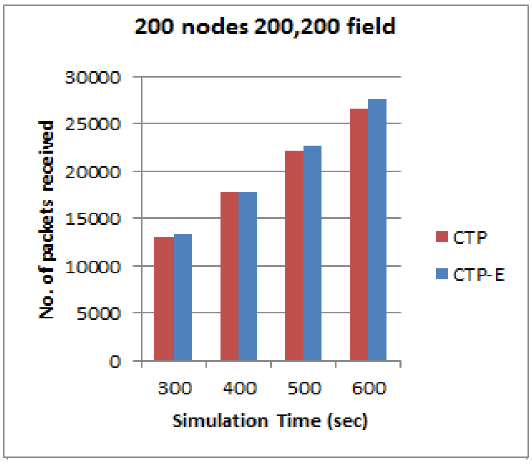

Figure 7.18: Simulation for field size 200,200 (meters)

Figure 7.19: Comparison of existing CTP and CTP-E

There is more improvement for smaller field and less improvement for bigger field size for the CTP-E as shown in figure 7.19. As nodes are deployed near to each other the more possible routes are available.

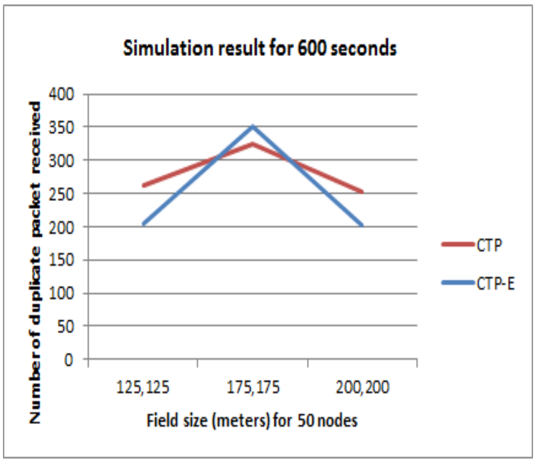

Figure 7.20: Simulation for 50 nodes

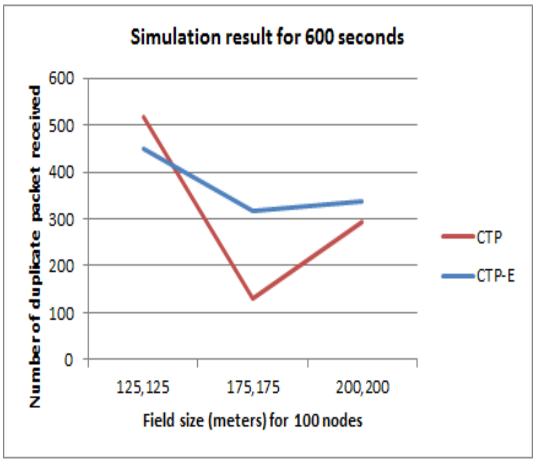

Figure 7.21: Simulation for 100 nodes

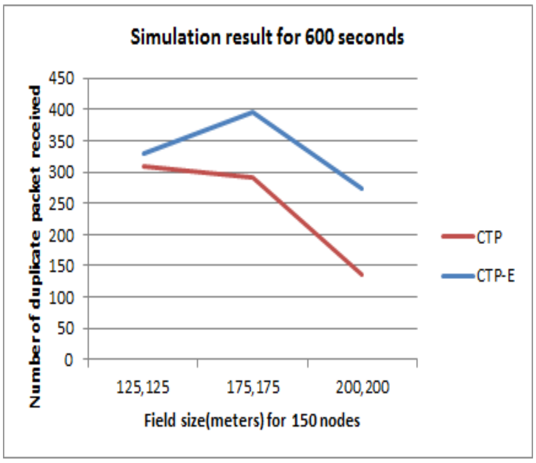

Figure 7.22: Simulation for 150 nodes

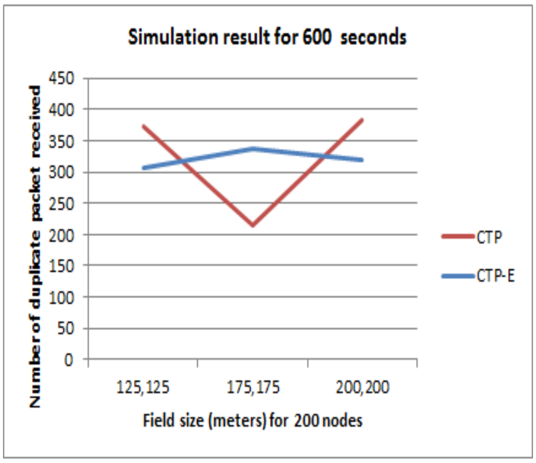

Figure 7.23: Simulation for 200 nodes

Figure 7.24: Comparison of duplicate packets in CTP and CTP-E

As from the figure 7.24 it is clear that CTP-E controls the sudden fall or rise of duplicate packets of CTP. CTP-E achieves higher throughput than CTP.

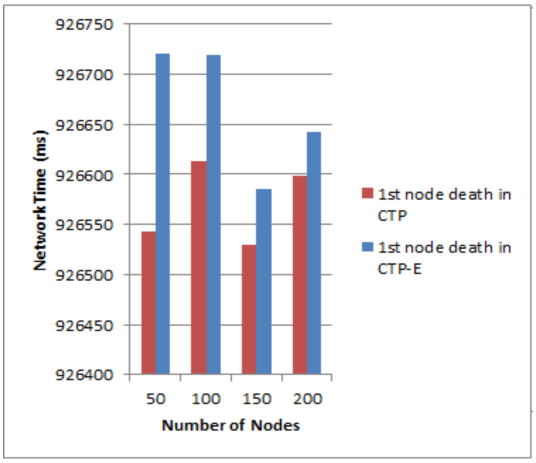

Figure 7.25: For field size 125,125 (meters)

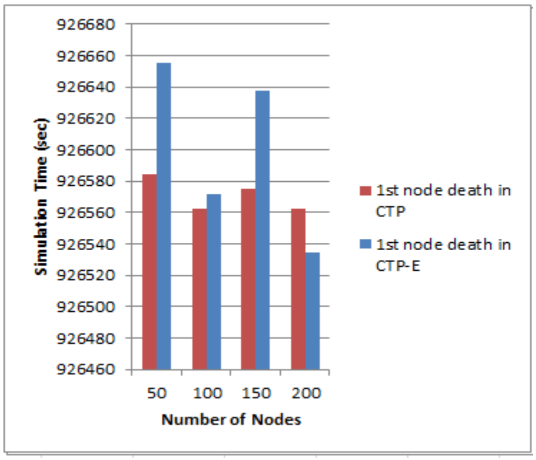

Figure 7.26: For field size 200,200 (meters)

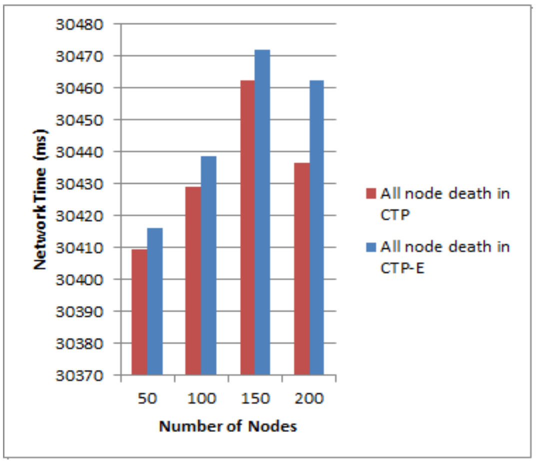

Figure 7.27: Network lifetime 125,125 (meters) field

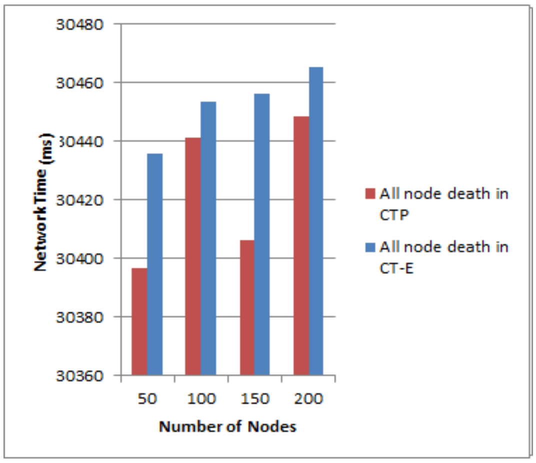

Figure 7.28: Network lifetime 200,200 (meters) field

Figure 7.29: Comparison of Network lifetime of CTP and CTP-E

As from the figure 7.29 the nodes last for more time in CTP-E than CTP, as residual energy is taken into consideration for selecting parent for forwarding packet to the sink node.

7.1.2 Simulation comparison for CTP and CTP-ER

As the beacon sending interval is doubled on each successful transmission the update of the parent's residual energy is received after long time which may result in draining the energy of the current parent. So This recovery bit is added for two reasons

1. To increase network lifetime.

2. For better throughput.

In this sub-section, the total Number of Packets received, Duplicate packets, Consumed energy and Network Lifetime of the original CTP and CTP-ER (Recovery bit added CTP) have been analyzed.

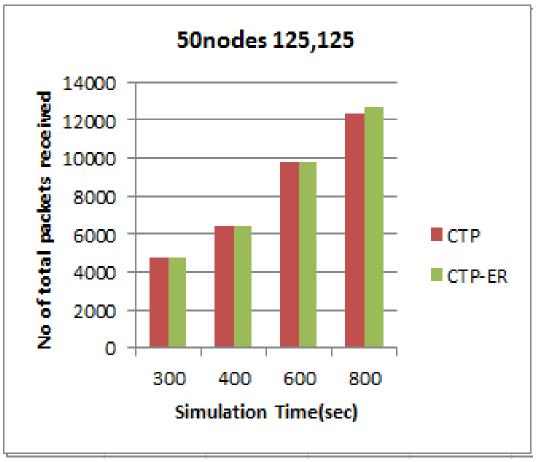

Figure 7.30: Simulation for field size 125,125 (meters)

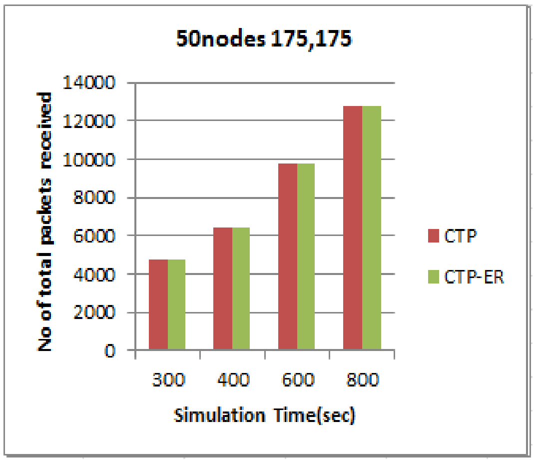

Figure 7.31: Simulation for field size 175,175 (meters)

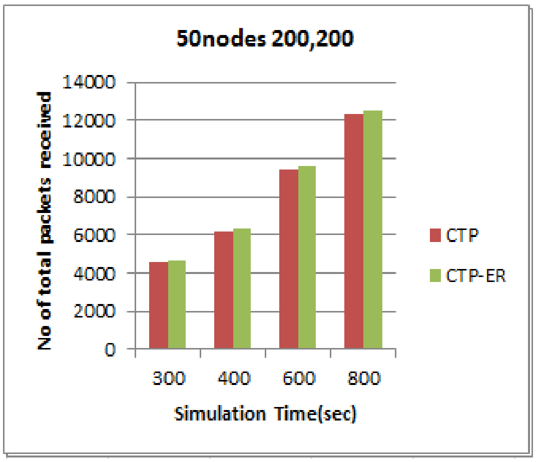

Figure 7.32: Simulation for field size 200,200 (meters)

Figure 7.33: Comparison of existing CTP and CTP-ER

Figure 7.33 shows the comparison of 50 nodes with varying scenarios for the total number of packets received. The total packets received is more when the recovery bit is added in the reserved bit of data packet along with the consideration of residual energy for parent selection.

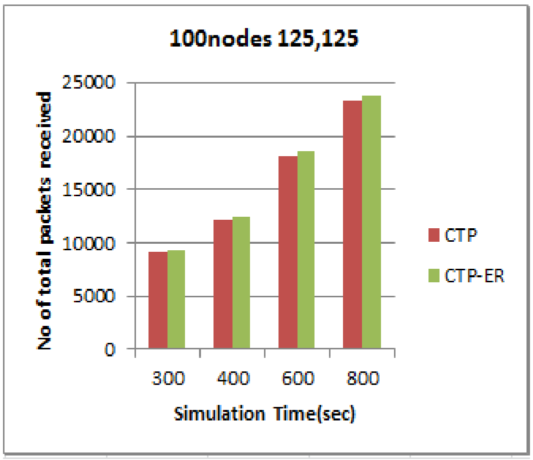

Figure 7.34: Simulation for field size 125,125 (meters)

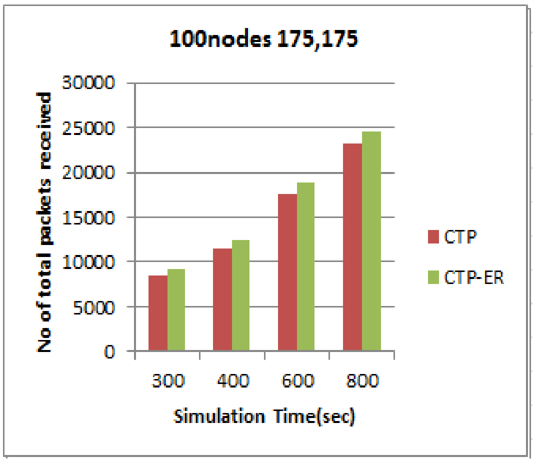

Figure 7.35: Simulation for field size 175,175 (meters)

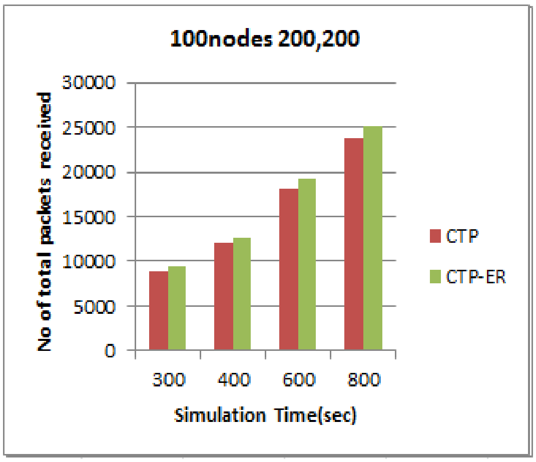

Figure 7.36: Simulation for field size 200,200 (meters)

Figure 7.37: Comparison of existing CTP and CTP-ER

The total number of packets received is more in CTP-ER compared to CTP shown in figure 7.37.

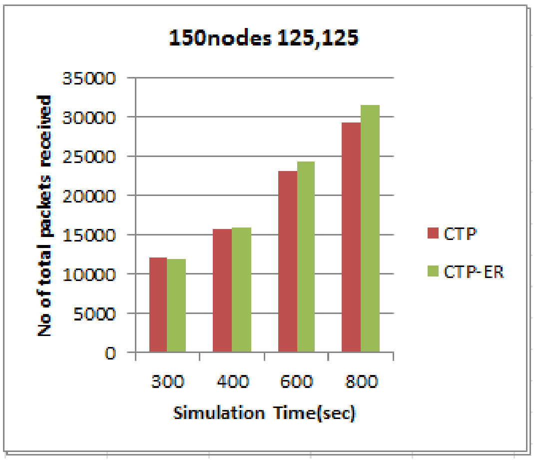

Figure 7.38: Simulation for field size 125,125 (meters)

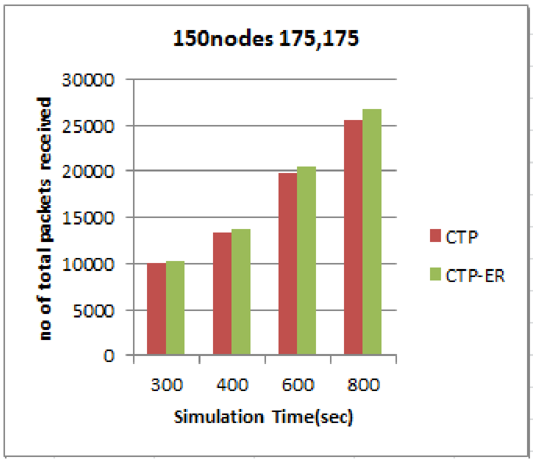

Figure 7.39: Simulation for field size 175,175 (meters)

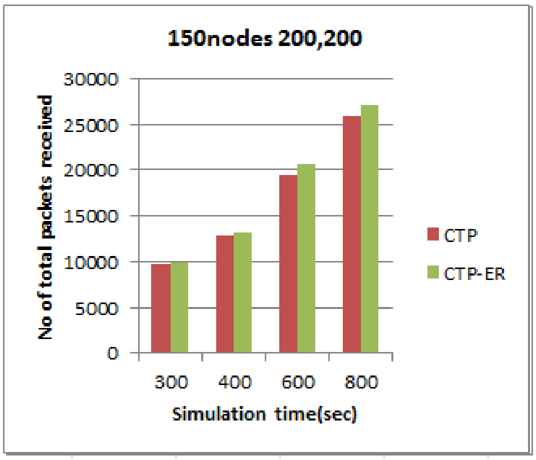

Figure 7.40: Simulation for field size 200,200 (meters)

Figure 7.41: Comparison of existing CTP and CTP-ER

As from the figure 7.41 CTP-ER is better than original CTP. As after removing the count of duplicate packets it is having much more packets than original routing protocol.

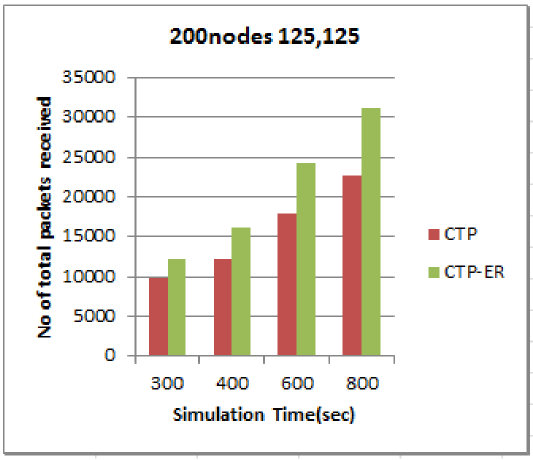

Figure 7.42: Simulation for field size 125,125 (meters)

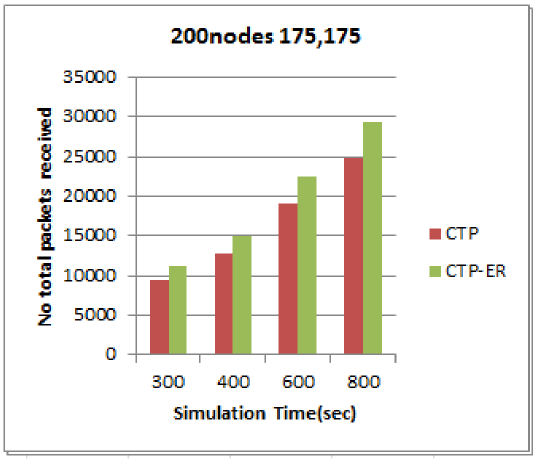

Figure 7.43: Simulation for field size 175,175 (meters)

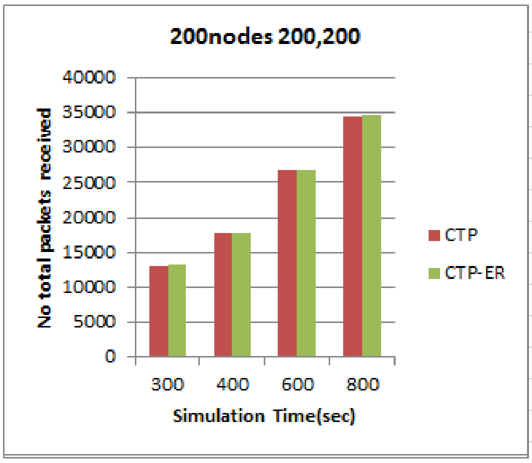

Figure 7.44: Simulation for field size 200,200 (meters)

Figure 7.45: Comparison of existing CTP and CTP-ER

For 200 nodes also the CTP-ER has higher throughput compared to original CTP shown in figure 7.45. And also the duplicate packet received in CTP-ER is less than CTP so overall successful packet reception is higher.

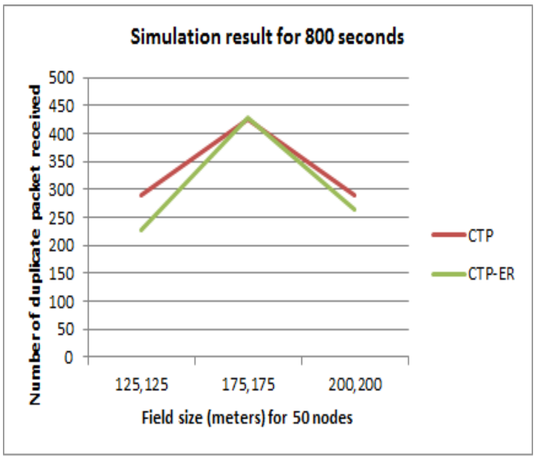

Figure 7.46: Simulation for 50 nodes

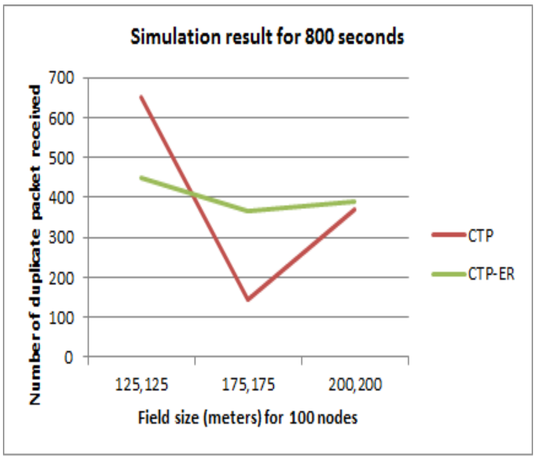

Figure 7.47: Simulation for 100 nodes

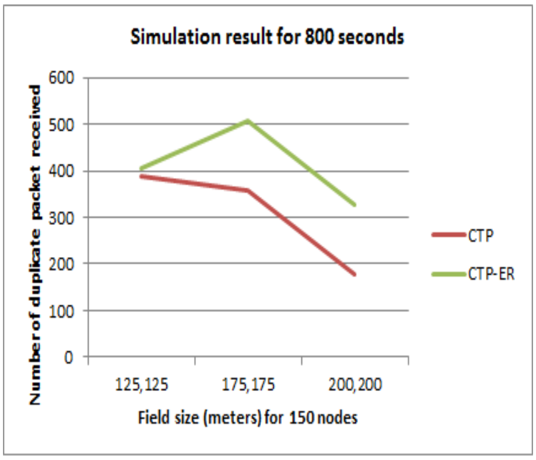

Figure 7.48: Simulation for 150 nodes

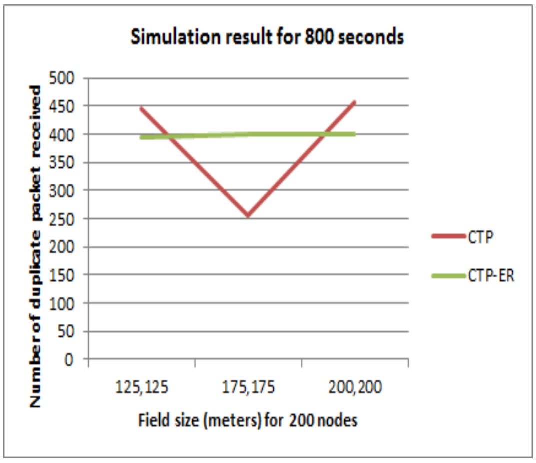

Figure 7.49: Simulation for 200 nodes

Figure 7.50: Comparison of duplicate packets in CTP and CTP-ER

As shown in figure 7.50 CTP shows abrupt change in number of duplicate packet received as field size is increased. But CTP-ER is receiving less duplicate packets in almost all varying scenarios. Only for 150 nodes it is receiving more duplicate packets than CTP. But the overall throughput is higher for CTP-ER.

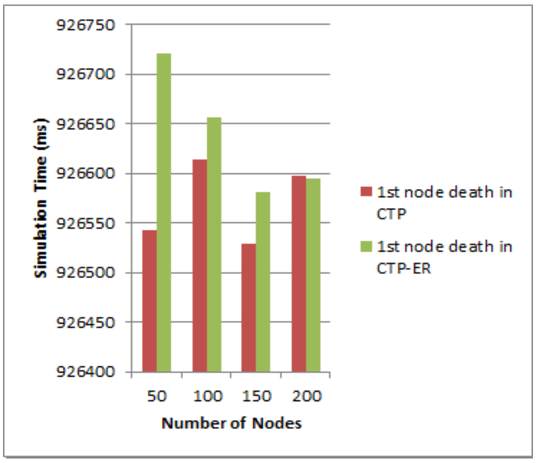

Figure 7.51: For field size 125,125 (meters)

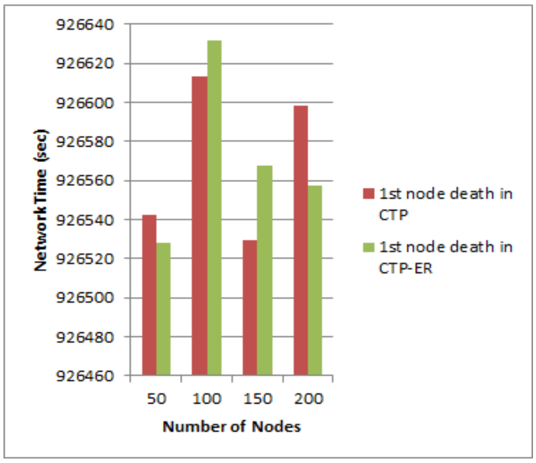

Figure 7.52: For field size 200,200 (meters)

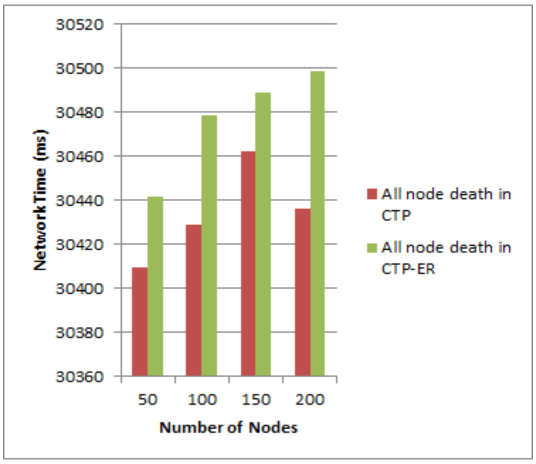

Figure 7.53: Network lifetime 125,125 (meters) field

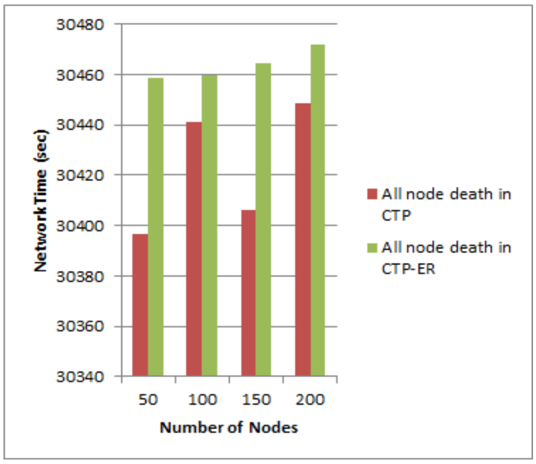

Figure 7.54: Network lifetime 200,200 (meters) field

Figure 7.55: Comparison of Network lifetime of CTP and CTP-ER

Thus from all the comparison showed in this sub-section it is analyzed that CTP-ER is better than CTP.

7.1.3 Simulation comparison for CTP and CTP-S

In this sub-section, the total Number of Packets received, Duplicate packets, Consumed energy of the CTP and CTP-S (Suggested parent) are compared.

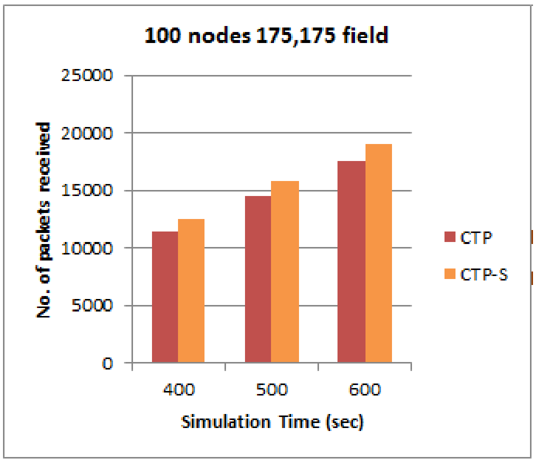

Figure 7.56: Simulation for field size 175,175 (meters)

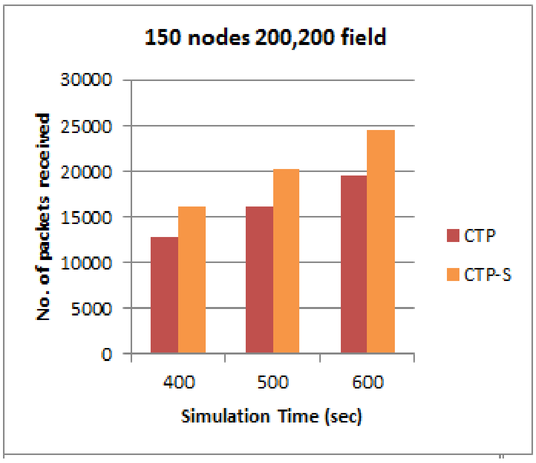

Figure 7.57: Simulation for field size 200,200 (meters)

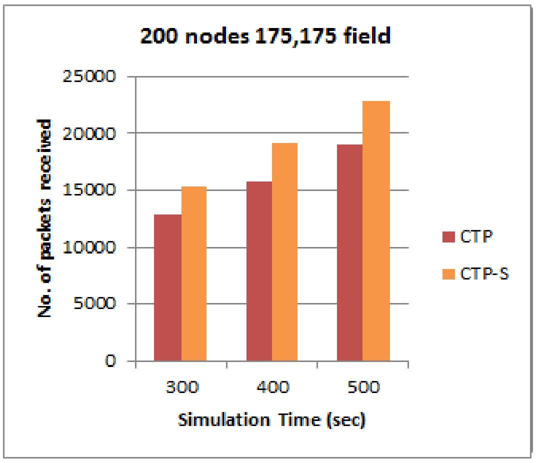

Figure 7.58: Simulation for field size 175,175 (meters)

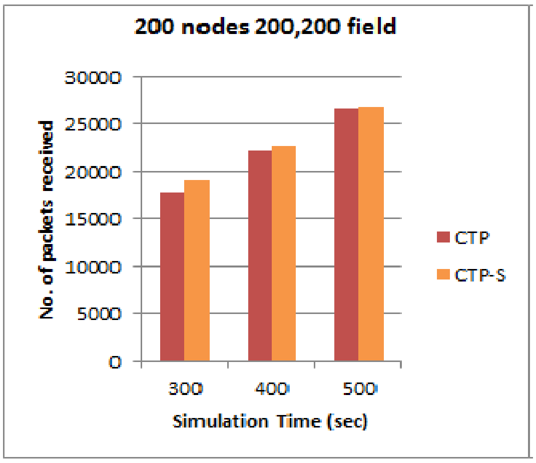

Figure 7.59: Simulation for field size 200,200 (meters)

Figure 7.60: Comparison of existing CTP and CTP-S

As shown in figure 7.60 the total packets received are much higher when the queue length and quality inbound link is used for selecting the parent node.

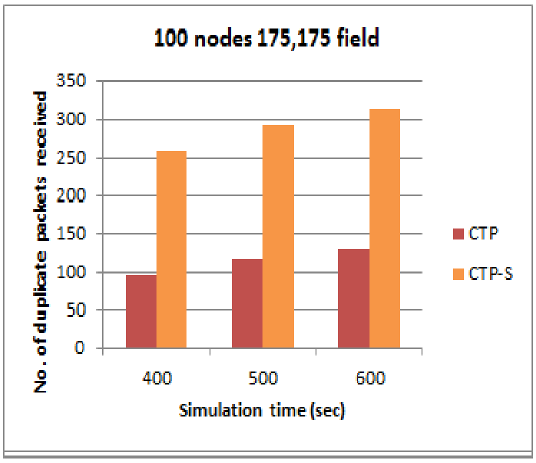

Figure 7.61: Simulation for field size 175,175 (meters)

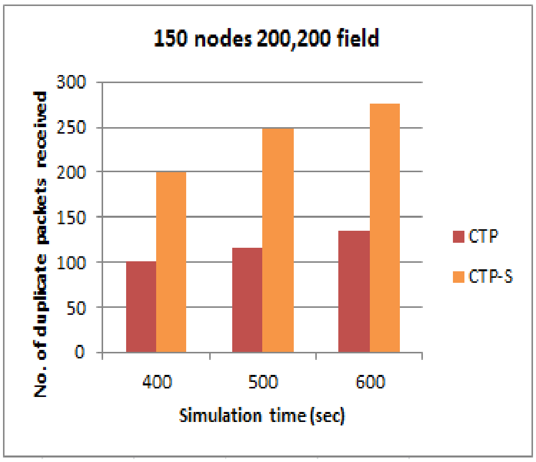

Figure 7.62: Simulation for field size 200,200 (meters)

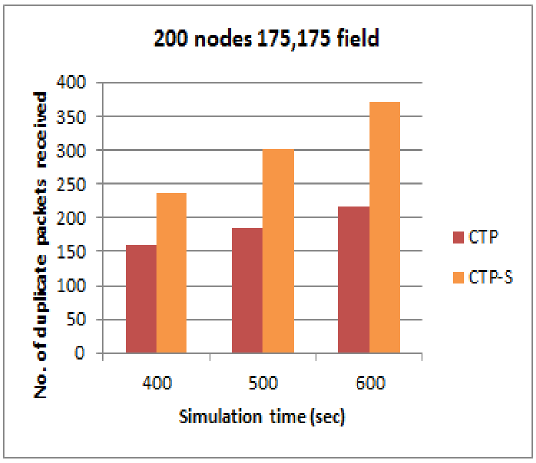

Figure 7.63: Simulation for field size 175,175 (meters)

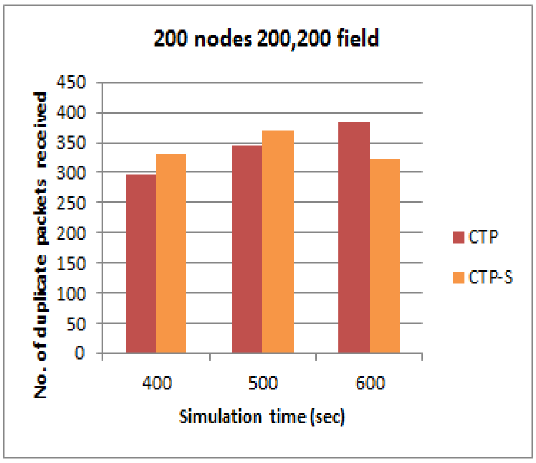

Figure 7.64: Simulation for field size 200,200 (meters)

Figure 7.65: Comparison of existing CTP and CTP-S

As from the figure 7.65 this new approach has a drawback that the received number of duplicate packet is more than the original CTP. But the overall throughput is still higher for CTP-S than CTP.

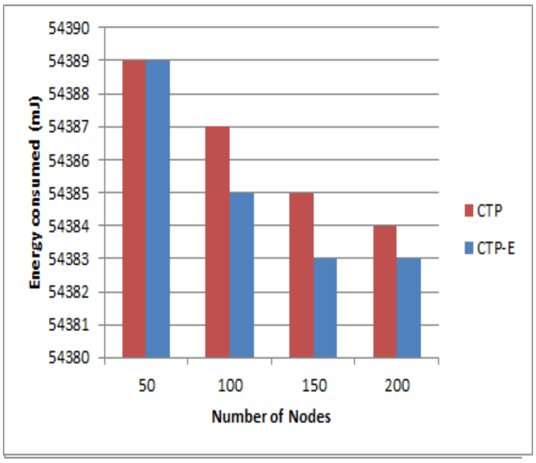

Figure 7.66: Simulation results for 800 seconds with field size 200,200 (meters)

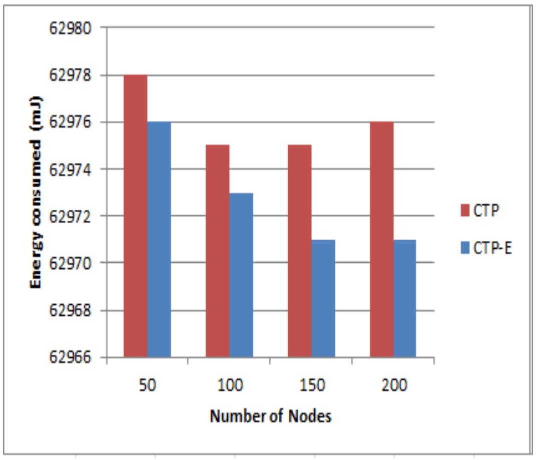

Figure 7.67: Simulation results for 1000 seconds with field size 200,200 (meters)

Figure 7.68: Comparison of existing CTP and CTP-E

It is clear from the above figure 7.68 that the energy consumption in CTP-E is less than the CTP. Though not much difference is seen but it still affects the lifetime of the network.

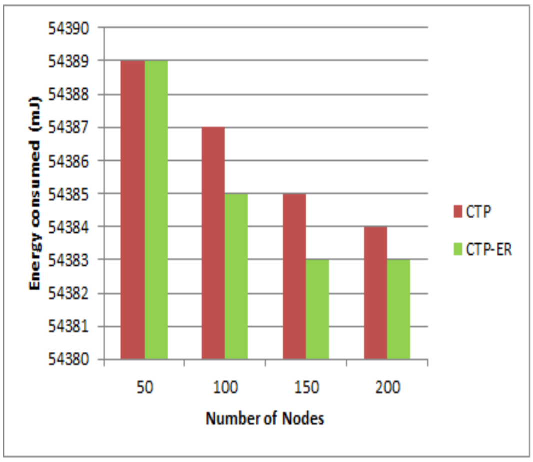

Figure 7.69: Simulation results for 800 seconds with field size 200,200 (meters)

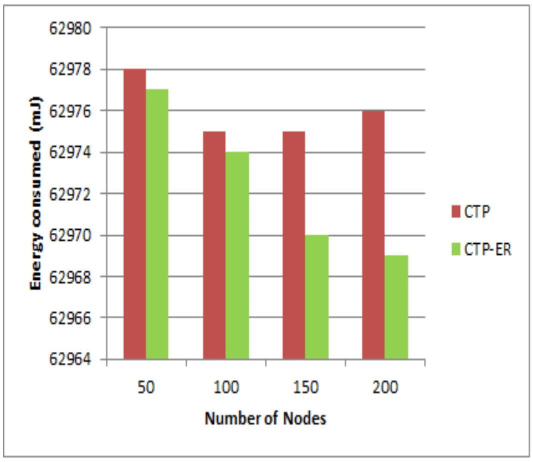

Figure 7.70: Simulation results for 1000 seconds with field size 200,200 (meters)

Figure 7.71: Comparison of existing CTP and CTP-ER

The energy consumption is lesser in CTP-ER compared to CTP. And hence in physical world the simulation or experiment may run for longer time, So for that this small change of CTP-ER will have high efficiency than CTP.

Chapter 8

Conclusion and Future Work

Energy is key constraint for Wireless Sensor Network. The residual energy is taken into consideration for parent selection procedure as to keep network alive. In this thesis the CTP tree construction procedure is analyzed and found the problem of its rapid energy drain in parent node due to repetitive selection the same node as parent node. To overcome this problem the energy constraint is introduced in the existing tree construction procedure. And the results are analyzed against the results of original CTP.

The another problem of late recognition of the link breakage which reduces network lifetime and increases the latency. To overcome this problem the recovery packet has been introduced so that node can be aware of its parent energy value in advance. And the results are analyzed and compared against the original CTP.

The node ability to pass the packet is also taken into consideration for selecting to parent. As packet can be dropped by node also along with the link. So parent selection is based on current load and past history and residual energy. The results are compared with CTP results. And the simulation results showed that our algorithm gives improved performance for total packet received, consumed energy, network lifetime, duplicate packet received. And this approach of selecting parent based on past history and current load can be further optimized to improve network lifetime, latency.

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